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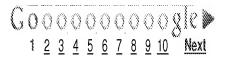
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# **FIR Filter Structures**

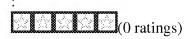
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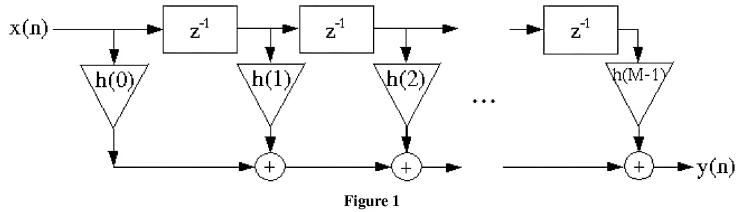
Summary: The direct-form and transpose-form structures are most commonly used to implement FIR filters. For certain special filters, recursive implementations require less computation. Lattice and cascade structures are occasionally also used.

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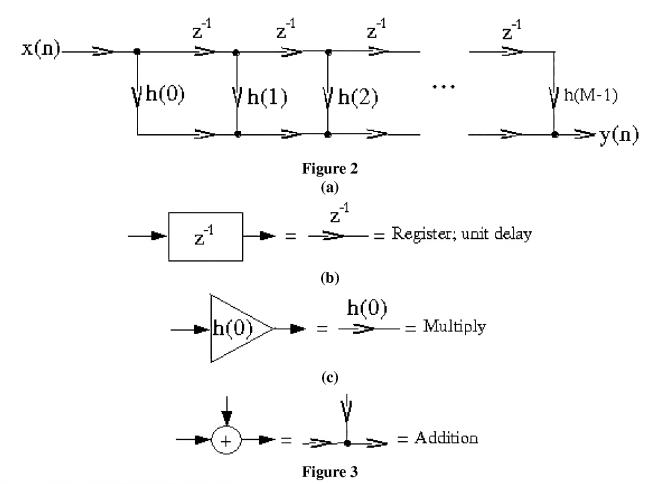
Consider causal FIR filters: y(n) =

$$M-1$$
 $\sum_{k=0}$ 

(h(k) x(n-k)); this can be realized using the following structure



or in a different notation



This is called the *direct-form FIR filter structure*.

There are no closed loops (no feedback) in this structure, so it is called a *non-recursive structure*. Since any FIR filter can be implemented using the direct-form, non-recursive structure, it is always possible to implement an FIR filter non-recursively. However, it is also possible to implement an FIR filter *recursively*, and for some special sets of FIR filter coefficients this is much more efficient.

# **Example 1**

$$y(n) =$$

$$M-1$$

$$\sum_{k=0}$$

(x(n-k)) where  $h(k) = \{0,0,1,1,...,1,1,0,0,0,...\}$  But note that y(n) = y(n-1) + x(n) - x(n-M) This can be implemented as

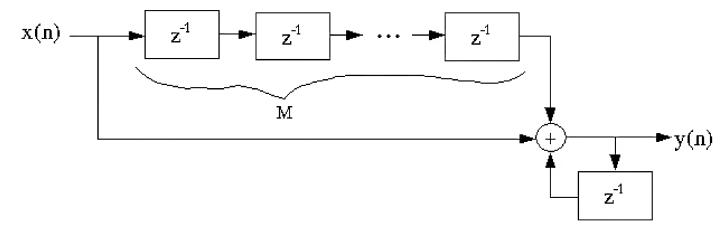


Figure 4

Instead of costing M-1 adds/output point, this comb filter costs only two adds/output.

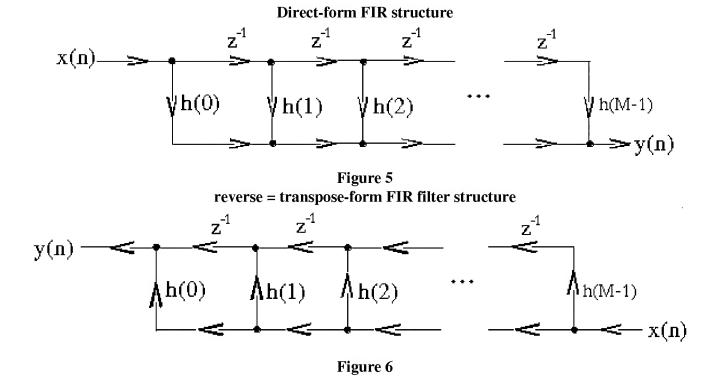
## **Exercise 1**

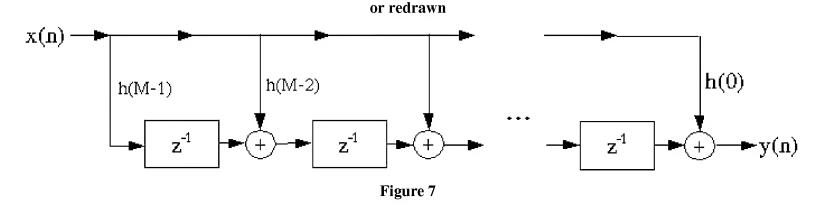
Is this stable, and if not, how can it be made so?

IIR filters must be implemented with a *recursive* structure, since that's the only way a finite number of elements can generate an infinite-length impulse response in a linear, time-invariant (LTI) system. Recursive structures have the advantages of being able to implement IIR systems, and sometimes greater computational efficiency, but the disadvantages of possible instability, limit cycles, and other deletorious effects that we will study shortly.

# Transpose-form FIR filter structures

The *flow-graph-reversal theorem* says that if one changes the directions of all the arrows, and inputs at the output and takes the output from the input of a reversed flow-graph, the new system has an identical input-output relationship to the original flow-graph.





## Cascade structures

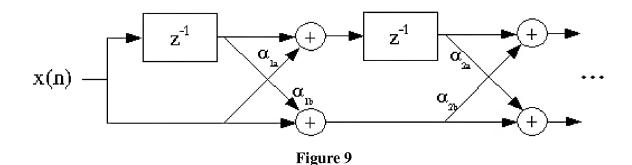
The z-transform of an FIR filter can be factored into a cascade of short-length filters  $b_0 + b_1 z^{-1} + b_2 z^{-3} + ... + b_m z^{-m} = b_0 (1 - z_1 z^{-1})$  (1  $-z_2 z^{-1}$ ) ...  $(1 - z_m z^{-1})$  where the  $z_i$  are the zeros of this polynomial. Since the coefficients of the polynomial are usually real, the roots are usually complex-conjugate pairs, so we generally combine  $(1 - z_i z^{-1})$   $(1 - z_i z^{-1})$  into one quadratic (length-2) section with real coefficients  $(1 - z_i z^{-1})$   $(1 - z_i z^{-1})$  (1 -

Figure 8

This is occasionally done in FIR filter implementation when one or more of the short-length filters can be implemented efficiently.

### **Lattice Structure**

It is also possible to implement FIR filters in a lattice structure: this is sometimes used in adaptive filtering



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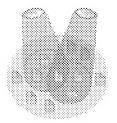
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